GRANITE AS DIMENSION STONE

BY OLIVER BOWLES

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INTRODUCTION

From remote antiquity stone has been employed for structural, ornamental, and memorial purposes. It was, and still is, so used because of its availability in innumerable localities and its architectural adaptability, dignity, substantiality, and durability. The principal varieties of stone used are granite, marble, limestone, sandstone, and slate. This report deals with granite.

OCCURRENCE AND CHARACTER OF GRANITE

Granites usually have been classed as igneous rocks derived from molten masses or magmas, but there is wide evidence that the origin of some granites may be attributed to regional metamorphism of preexisting rocks, rearrangement and recrystallization taking place without a liquid or molten stage. In any event granitization is a slow, deep-seated process.

In general, rapid crystallization results in a fine-grained texture - molten lavas may solidify so quickly that they form glassy rocks. Slow crystallization, on the other hand, tends to produce coarse-grained rocks. Many granites are of this type. They are regarded as having attained their solid form at considerable depth below the surface of the earth under conditions of high temperature and pressure. The constituent minerals crystallized slowly, the crystals interlocking with each other. However, some granites that crystallized more rapidly are fine-grained.

Although most granites were formed deep in the earth, long geologic ages of earth movement and rock folding have elevated them in many places to points at or near the surface of the earth, where they are available for commercial use. The overlying formations may have been removed by erosion or glaciation, so that the granites are exposed.

The chief minerals of which granites are formed are feldspars and quartz and smaller amounts of mica and hornblende. Granites are characterized by massive, homogeneous texture. They are classified as fine-grained, medium-grained, or coarse-grained. Medium-grained granites are those in which the feldspar crystals average about one-fourth inch in diameter. If relatively coarse grained crystals appear in a fine-grained groundmass the rock is designated as porphyritic granite. Uniformity in texture and grain size is desirable in building and ornamental stones, although occasionally rocks of variable texture, such as the porphyritic granites, are used. A rock may have the mineral constituents of a granite but may show a banded or platy structure owing to recrystallization, folding, or other changes while the rock was in a plastic or semimolten condition. Such metamorphic rocks are called granite gneisses. They are used at times for building purposes but not as commonly as the uniformly textured granites.

Granites are named from the most abundant mineral - other than quartz and feldspar - that they contain, being called, for example, biotite granite or hornblende granite.

Dark igneous rocks, classified petrographically as diorite, gabbro, or diabase, are sometimes utilized as dimension stone, chiefly for memorial purposes, and they are classed commercially as black granites.

The question is sometimes raised as to the depth to which a granite occurrence may extend. In this respect granites differ notably from limestone, sandstone, or other sedimentary rocks. The sediments were originally laid down in relatively thin beds, and individual formations providing rock of economic value are seldom over 200 or 300 feet thick. On the other hand, granites extend to unknown depths that may be measurable in miles. Reserves of granite are to be measured therefore by their area and by the depth to which they can be worked economically. Exceptional granites of commercial quality may occur in sills or sheets of limited thickness, with rocks of different character beneath them, as, for example, at Westerly, R. I., and Niantic, Conn.

PHYSICAL AND CHEMICAL PROPERTIES

All essential constituents of granite except mica are very hard; therefore granites are difficult to cut and dress. Granites are usually red, pink, gray, or almost white, depending upon the color of the feldspars. If hornblende or biotite (black mica) is abundant, the rock may be dark green or almost black.

Granite is very strong. Structural granite that is sound and suitable in other respects is strong enough for any ordinary use. Bridge piers, arches, and the bases of tall monuments on buildings must sustain heavy pressure, but even in such structures the strength of ordinary granite far exceeds the requirements of safety. The weight of a column of granite 600 feet high would exert a pressure of only about 700 pounds per square inch on its base, and high-grade granites will sustain crushing loads of 17,000 to 30,000 pounds per square inch.

Granites are notably impervious to moisture. The ratio of absorption is only a fraction of 1 percent.

Figures for compressive strength and absorption of various granites have been published by the National Bureau of Standards(7).[2]

Granite is one of the most durable of all building materials since the quartz and feldspar are highly resistant to normal weathering. Feldspars will, however, disintegrate slowly if exposed to an acid-bearing atmosphere, as in regions where coal smoke is prevalent. All granites disintegrate very slowly under repeated contraction and expansion due to diurnal and seasonal temperature changes, but under ordinary atmospheric conditions granite will endure for centuries without significant change in color or durability.

Table 1 indicates the mineralogical and chemical composition of typical commercial granites. The data were obtained from reports of the National Bureau of Standards, bulletins of the Federal Geological Survey, State Geological Survey reports, and various textbooks.

2/ Underlined numbers in parentheses refer to items in the bibliography at the end of this report.

TABLE 1. - Mineralogical and chemical composition of granites

Source	Minerals present[1]	Chemical composition					
		SiO_2	Al_2O_3	Fe_2O_3 FeO	K_2O	Na_2O	CaO
North Jay, Maine	Microcline and orthoclase, quartz, oligoclase, biotite	71.5	14.2	1.9	4.7	3.4	1.0
W. Chelmsford, Mass.	Orthoclase, quartz, plagioclase, muscovite, biotite	74.7	13.6	1.2	4.4	3.9	-
Concord, N. H.	do.	74.5	14.2	2.4	4.1	2.0	1.7
Waterford, Conn.	Oligoclase, microcline, quartz, biotite	68.1	14.3	2.6	5.7	6.6	1.9
Barre, Vt.	Orthoclase, microcline, quartz, oligoclase, biotite	70.0	15.4	2.7	4.3	5.4	1.8
Mt. Airy, N. C.	Orthoclase, microcline, plagioclase, quartz, biotite	70.7	16.5	2.4	2.4	4.6	3.0
Lithonia, Ga.	Quartz, orthoclase, microcline, oligoclase, biotite	76.0	13.1	.9	4.7	3.9	1.1
Rockville, Minn.	Orthoclase, quartz, plagioclase, biotite	69.6	13.9	4.6	4.3	2.3	2.6
Morton, Minn.	Orthoclase and plagioclase, quartz, biotite, hornblende	71.6	14.0	2.3	3.9	3.8	2.0
Llano, Tex.	Albite, quartz, orthoclase, anorthite, corundum	70.2	17.4	3.2	2.9	4.3	1.5
Elberton, Georgia	Orthoclase and microcline, oligoclase, quartz, biotite	70.4	16.5	1.2	5.6	5.0	1.7

[1] In descending order of abundance.

TYPES OF PRODUCTS

Granite quarries fall logically into two groups - those producing broken or crushed stone and those producing dimension stone. The quarries of the first group provide irregular fragments of various sizes, whereas the products of the second group of quarries are sawed or otherwise cut or broken to specific sizes and shapes. The larger products of the broken-stone quarries consist of riprap for railroad or highway fills, shore protection, spillways at dams, breakwaters, and similar applications where large, irregular blocks may be employed. The smaller products consist of crushed stone of various sizes for use in stucco or terrazzo and granite dust. The chief dimension-stone products are cut stone (including ashlar), rough building blocks, house veneer, massive rectangular blocks for piers and seawalls, monumental stone, columns, bases, sills and various other structural members, and paving stones, curbing, and flagging.

It seems logical to divide the quarries into these two groups because their manufacturing and marketing problems are dissimilar. In quarrying broken stone, heavy charges of explosives are used, the stone is loaded with power shovels, crushed, and screened, and the products are sold chiefly for road construction, concrete aggregate, or railroad ballast. In dimension-stone quarries explosives are used very sparingly, the rock masses are shaped to definite forms and sizes, and the rock surfaces may be finished by some process such as tooling or polishing. A few dimension-stone-quarry operators, however, manufacture crushed-stone products from quarry or mill waste, and such manufacturers are of course interested in the problems of both groups.

This paper is concerned primarily with the dimension-stone group.

USES

Granite quarries producing dimension stone may be divided into three groups: (1) Those producing building stone, (2) those producing memorial stone, and (3) those producing paving blocks and curbing. These groups are not distinct, independent units. Memorial stones may consist of single blocks, or of two or more blocks such as bases and dies, or they may be used to construct large and elaborate mausoleums or monuments that might be classed as buildings. On the other hand, granite used in buildings, although consisting chiefly of unpolished stone, includes also polished columns, polished base courses, and decorative units manufactured in the same way and with the same surface finish as memorial stone. Two or more types of products may originate in a single quarry, but usually 1 of the 3 groups mentioned above predominates as the product of a single establishment.

HISTORY OF PRODUCTION

Table 2 shows the history of production of block granite from 1919 to 1953. Some significant changes have taken place in these 35 years. The most striking is virtual disappearance of paving-block manufacture, which was in early years a major branch of the granite industry. The 680,000 blocks made in 1952 is only 1-1/2 percent of the 41 million blocks made in 1923. The decline in the use of paving blocks is due primarily to substitution of concrete for pavements.

Curbing manufacture has declined moderately. Granite curbs are still preferred at road and street corners and in other places where traffic and corrosion conditions are usually severe. Sales of rubble, the roughest form of building stone, have declined because of competition with concrete for basement walls, retaining walls, and similar uses.

Building-granite sales dropped during the industrial depression of the early 1930's to about one-third of the volume sold during the late 1920's. There was a moderate postdepression recovery; but, as building stone was regarded as unessential from a military standpoint, the industry declined greatly during World War II. The postwar recovery reached about half of the volume of sales concluded during the years immediately preceding World War II. A factor that has retarded recovery has been the employment of hand operations in some branches of stone fabrication. Although much progress has been made in mechanization, it is difficult to establish automatic machine methods in stoneworking.

Memorial-stone sales have been maintained at a relatively high level. In contrast with the building-stone branch of the industry, the demand for memorials increased during the war and early postwar years. The great increase in value of memorial sales during recent years is noteworthy. Figure 1 shows the fluctuations from year to year in sales of building and memorial granite from 1919 to 1953.

DISTRIBUTION OF DEPOSITS

Granites adapted for use as dimension stone are available in many parts of the United States. From the standpoint of general distribution they are quarried in four chief areas as follows: (1) The Appalachian district of eastern United States from Maine to Georgia; (2) the Middle Western States, particularly South Dakota, Minnesota, Wisconsin, and Oklahoma; (3) the Rocky Mountain States, the deposits of which have not been developed extensively, and (4) the Pacific Coast States, particularly California. Granite is produced also in certain areas outside these four main territories. The principal deposits are described briefly by States in alphabetical order.

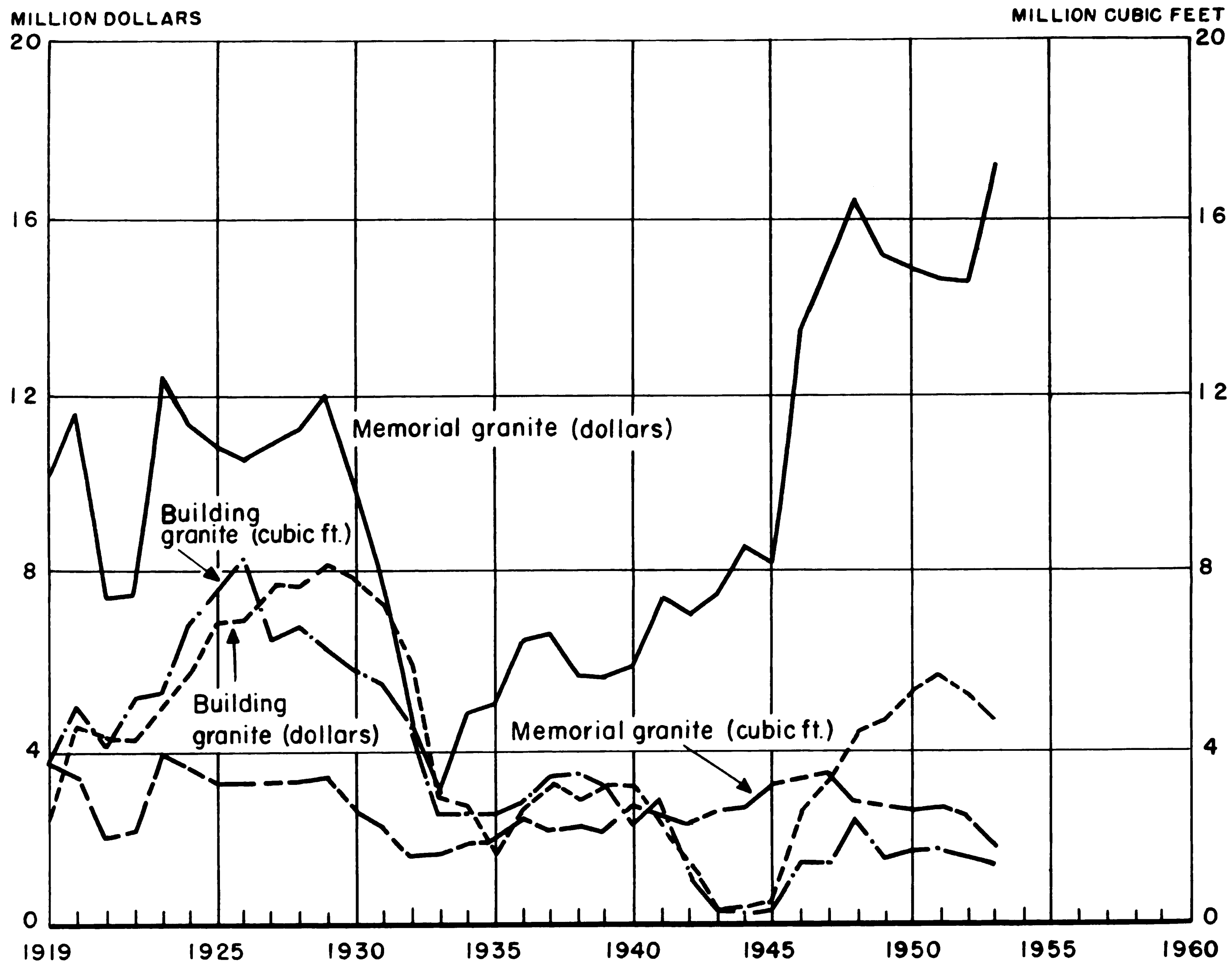

Figure 1. - Quantity and value of building and memorial granite sold, 1919-53.

TABLE 2. - Quantity and value of dimension granite sold in the United States, 1919-53

	Building stone		Monumental stone		Paving blocks		Curbing		Rubble		Total
	Thousand cubic feet	Value, thousand dollars	Thousand cubic feet	Value, thousand dollars	Number, in thousands	Value, thousand dollars	Quantity[1/]	Value, thousand dollars	Thousand short tons	Value, thousand dollars	Value, thousand dollars
1919	3,651	$2,268	3,658	$10,143	33,602	$2,370	823	$642	98	$141	$15,563
1920	4,896	4,492	3,379	11,543	32,230	2,583	998	756	91	154	19,528
1921	4,052	4,206	1,957	7,253	37,201	3,222	1,172	858	183	219	15,765
1922	5,058	4,247	2,086	7,429	25,693	2,233	1,408	900	175	221	15,030
1923	5,244	5,011	3,948	12,398	41,017	3,578	2,104	1,436	168	184	22,608
1924	6,845	5,664	3,521	11,447	37,599	3,284	2,252	1,513	235	243	22,152
1925	7,515	6,815	3,195	10,805	37,675	3,486	2,780	1,840	270	328	23,274
1926	8,182	6,884	3,241	10,533	37,148	3,223	3,503	2,402	122	182	23,225
1927	6,398	7,672	3,198	10,881	35,950	3,368	3,431	2,605	485	427	24,954
1928	6,704	7,671	3,173	11,217	32,949	2,935	3,548	2,607	311	321	24,753
1929	6,202	8,105	3,344	11,963	28,174	2,651	2,905	2,126	502	524	25,369
1930	5,707	7,800	2,639	9,894	27,248	2,348	2,299	1,768	271	225	22,036
1931	5,392	7,217	2,231	7,457	21,288	1,859	2,151	1,612	108	114	18,259
1932	4,395	5,873	1,606	4,575	6,804	563	1,071	693	39	39	11,743
1933	2,479	2,886	1,581	2,962	5,801	578	724	489	39	36	6,951
1934	2,514	2,643	1,827	4,752	5,838	614	868	603	66	74	8,686
1935	2,509	1,596	1,869	5,040	8,112	769	599	535	50	56	7,996
1936	2,620	2,629	2,478	6,441	6,826	703	1,190	1,206	77	118	11,097
1937	3,323	3,068	2,658	6,628	7,867	781	881	825	111	150	11,452
1938	3,417	2,805	2,093	5,651	4,165	453	895	742	108	127	9,778
1939	3,107	3,076	2,160	5,665	2,798	246	726	625	197	227	9,838
1940	2,179	3,092	2,109	5,907	1,813	236	569	564	240	289	10,088
1941	2,772	2,151	2,577	7,489	2,384	255	528	586	278	350	10,831
1942	994	1,162	2,443	7,093	1,987	189	201	232	216	404	9,081
1943	332	251	2,168	7,475	637	67	65	79	66	120	7,991
1944	211	272	2,508	8,595	649	45	153	128	44	89	9,129
1945	335	385	2,601	8,228	213	22	119	154	109	192	8,981
1946	1,377	2,507	3,195	13,433	579	50	315	458	131	263	16,712
1947	1,387	3,186	3,269	14,854	684	56	554	971	87	214	19,281
1948	2,366	4,335	3,327	16,459	392	33	699	1,260	110	237	22,323
1949	1,484	4,618	2,773	15,100	276	27	579	1,365	86	204	21,315
1950	1,690	5,172	2,667	14,947	348	51	901	2,278	118	318	22,767
1951	1,720	5,562	2,609	14,606	431	52	944	2,710	94	292	23,222
1952	1,535	5,244	2,509	14,458	683	38	975	2,374	103	284	22,397
1953	1,359	4,585	2,853	17,200	348	40	919	2,220	179	425	24,472

[1/] Thousands of lineal feet 1919 to 1934; thousands of cubic feet 1935 to 1953.

California

A light-gray granite specked with black mica crystals quarried at Raymond, Madera County, has been used extensively for architectural work. Building granites are produced also at Victorville, San Bernardino County, and both building and memorial granites near Rocklin, Placer County. Gray granite for the monumental trade is quarried near Lakeside and Escondido, San Diego County. Hornblende diorites classed as black granites are quarried at times near Porterville, Tulare County, and Perris, Riverside County.

Connecticut

The granite industry of Connecticut is centered chiefly in southern New London County. Buff, light-gray, and dark-gray granites are quarried for structural and ornamental uses near East Lyme, Niantic, Millstone, and Waterford.

Georgia

A fine-grained, gray granite gneiss is quarried at Lithonia, DeKalb County, for building stone, paving blocks, and curbing. Elberton, Elbert County, is the center of a memorial-stone industry that produces larger quantities of monumental granite than for any other State except Vermont. A medium-grained light-gray, a fine-grained dark, and a brownish-pink granite are produced. More than 20 quarries and finishing mills usually operate in this area.

Maine

Granites are widespread in Maine. In 1930 two-thirds of the output of block granite consisted of paving stones and curbing. Maine produced more than 40 percent of all the granite paving blocks made in the United States, but this branch of the industry has almost vanished. The principal products currently marketed are building and memorial stones and curbing. The largest quarries are in deposits of medium- to coarse-grained gray biotite granite near Stonington, Hancock County. Fine-grained gray granites are quarried at Frankfort, Waldo County, and Clark Island, Knox County. A light-gray almost white architectural granite is quarried at North Jay, southern Franklin County.

Massachusetts

One of the leading centers of building-granite production in the United States is the West Chelmsford, Westford, and Graniteville district of Middlesex County. The rock is a uniform gray granite that has a wide market range. Pink granite is quarried at Milford and light-gray granite at Uxbridge, both in Worcester County. A granite ranging from greenish gray to dark bluish gray is quarried near Quincy, Norfolk County. Quincy was at one time an important center of memorial-stone production, but the recent output has been relatively small. Green granite was quarried in past years at Cape Ann near Gloucester, Essex County.

Minnesota

Most granites produced in Minnesota are used for memorial purposes. They are quarried chiefly in the St. Cloud area, Stearns County, and in the Minnesota River Valley. Medium- to coarse-grained red granites are those used most widely for monumental stone. A coarse-grained, pinkish-gray, architectural granite is produced near Cold Spring and Rockville, Stearns County. A biotite-granite gneiss with distinct banding, quarried near Morton, Renville County, is used widely for polished base courses of large buildings. Pink and red granites, used to some extent for architecture but chiefly for memorials, are quarried near Ortonville, Big Stone County, and in Mille Lacs and St. Louis Counties.

New Hampshire

A fine-grained gray granite quarried near Concord, Merrimack County, is used extensively for building purposes. A fine-grained, blue-gray granite occurring near Milford, Hillsboro County, is applied chiefly to memorial uses. Both building and memorial granites are produced near Redstone and Conway, Carroll County. Two types are available - a pinkish-gray and a yellowish-green.

North Carolina

The most productive structural granite area in North Carolina is near Mount Airy, Surry County. The rock is a light-gray, almost white, biotite granite of medium texture and is used extensively for bridges and buildings. A pink granite quarried near Salisbury, Rowan County, is applied to both building and memorial uses.

Oklahoma

Memorial stones are quarried at Granite, Greer County, and Snyder, Kiowa County. The rocks of the former area are medium-grained red and pink. The prevailing type at Snyder is a fine- to medium-grained stone mottled pink and gray.

Pennsylvania

The black granites (diabase and gabbro) quarried at St. Peters, Chester County, and in western Bucks County near Coopersburg are used chiefly as memorial stones but are applied to some extent to building projects. The granite gneisses of the Philadelphia district have been used extensively for house veneer.

Rhode Island

A fine-grained pinkish or buff and a bluish-gray biotite granite are quarried near Westerly, Washington County, chiefly for memorials.

South Dakota

South Dakota has become one of the leading producers of memorial granite. The rock occurs in a belt that extends from Big Stone and Renville Counties, Minn., into Grant County, S. Dak. Quarries near Milbank and Bigstone City furnish granite characterized by a mahogany rather than a red color.

Texas

A coarse-grained, red granite quarried near Marble Falls, Burnet County, is used as architectural stone and also for jetties and breakwaters. A fine- to medium-grained gray granite quarried near Llano is used almost exclusively for memorials.

Vermont

A fine- to medium-grained gray to white biotite granite of uniform texture is quarried extensively near Barre, Washington County, for memorial uses. Much of it is fashioned into finished monuments in numerous mills in the Barre area. The stone has a wide market range. In value it exceeds that of any other State. Granite occurs in many other places in Vermont, and in past years was quarried extensively for building and memorial uses in Caledonia County (Ryegate granite), Windham County (Dummerston White), Windsor County (Bethel White), and various other localities.

Wisconsin

The reddish-brown to brilliant red granites of the Wausau district, Marathon County, the coarse-grained red to pale pink stones occurring near Amberg, Marinetta County, and the fine-grained, grayish-red to bright-red granites produced at Montello, Marquette County, are used chiefly for memorial stones, although they are used architecturally at times.

Other States

Dark-red granite is produced at Graniteville, Iron County, Mo.; a fine-grained gray biotite granite at Rion, Fairfield County, S. C.; and a bluish granite near Burksville, Nattaway County, Va.

Figures for production of granite in the form of dimension stone by States, insofar as they may be shown, appear each year in the Stone chapter of the Minerals Yearbook, volume I, published by the Bureau of Mines.

DESIRABLE QUALITIES OF A DEPOSIT

Granites occur widely in the United States and foreign countries. Single masses, as indicated by numerous related outcrops, may extend over more than a thousand square miles. Relatively few of these occurrences, however, have the qualities, locations, or working conditions requisite to adapt them to industrial uses as dimension stone.

The quality of the rock is of first importance. An even-grained uniform texture, and an attractive color are desirable. Uniformity in texture may be marred by the presence of undesirable streaks or spots. Such defects may consist of black knots, which are of two types: (1) Segregations of dark-colored minerals, such as mica or hornblende, into spots or streaks and (2) inclusions of dark rock fragments. Narrow diabase or trap dikes may appear as dark bands across the granite, and aplite, a fine-grained, light-colored granite, may form white dikes. The presence of dikes of either kind usually condemns the rock for structural or ornamental uses. Fine black or green lines, known as hairlines, appear on some granites. Knots or hairlines are permissible in granite used for paving blocks, curbing, and unpolished building stone. For the more ornamental applications where the surfaces are polished, rock having such defects must be avoided, because the imperfections stand out prominently on polished surfaces.

Most granite masses are intersected by cracks or joints, usually approaching a vertical direction. The most favorable condition is one in which the joints are spaced several feet apart and are in two parallel systems approximately at right angles to each other. If joints are closely spaced or irregular in direction, blocks of adequate size may be unobtainable, and the waste may be excessive.

The depth of overburden is an important factor. The presence of 30 or more feet of soil over the rock adds considerably to quarry expense. A bare outcrop is usually regarded as most favorable. However, the protection of several feet of soil is sometimes found to be advantageous. Although granites usually resist exposure remarkably well, the weathering effects of many centuries on exposed outcrops may bleach the color or cause some disintegration to a depth of several feet. This upper layer of defective rock must be removed as waste, and its removal is much more costly than the disposal of an equal volume of soil. It has been found in some places that the protection of 5 to 10 feet of soil has so preserved the rock that it may be used for building purposes almost to the surface.

ECONOMIC CONDITIONS

Drainage conditions have a direct bearing on production costs. The shelf or side-hill quarry providing automatic drainage is most desirable. On the other hand, a pit quarry demands pumping expense.

Many high-quality granites in minable locations are unused because they are remote from profitable markets or have unfavorable transportation or power facilities. The high-priced ornamental rock has a wider market range than the lower priced, unpolished, building granites. The success of a granite enterprise depends to a large extent on its ability to meet popular demands regarding color and texture.

QUARRY METHODS

Stripping

Removal of overburden (stripping) is the first step in opening a granite quarry. The overlying material may vary in thickness from a few inches to several feet. There are various methods of removal, and the choice is governed largely by quarry conditions. The more important types of equipment are hydraulic monitors, dragline scrapers, bulldozers, clamshell buckets worked from a derrick arm, and power shovels. For heavy stripping several types of large earth-moving machines are now available. Hydraulic stripping often is the least costly but can be used only where conditions are favorable, the chief requirements being an adequate water supply and favorable drainage to a waste-disposal area. If the surface rock is inferior it may be removed by blasting, but great care must be taken to avoid shattering the underlying serviceable rock.

Relief From Strain

When stripping is completed the next step is to separate and remove the quarry blocks. In shelf or side-hill quarries the operations are relatively simple. In pit quarries a difficult problem commonly encountered is a condition of strain or compression in the rock mass. If a row of closely spaced holes is drilled in such a mass of rock it may expand, crush the webs between the holes, and partly close the holes. If this takes place during the drilling process the drill bit may be pinched and rendered immovable. Before normal quarry operations can be conducted it is imperative that the strain be relieved.

At West Chelmsford, Mass., a method of strain relief used for many years is to drill 52-inch calyx drill holes in a line at right angles to the direction of compression, leaving a web of granite 4 to 6 inches wide between the holes. The expansive force of the rock is enough to crush the webs. An expansion of 1/2-inch in a mass of rock 100 feet long is common, and considerably greater expansion has been noted at times. Incidentally, the 52-inch drums of granite made with the calyx drill may be utilized by quartering them and making them into corner curbstones.

The latest method of obtaining relief from strain in this quarry is to cut an 8-inch channel with a flame drill, a method more commonly known as jet piercing. Combustion of oxygen (liquid oxygen is brought to the quarry in tank trucks) and fuel oil fed through a nozzle generates a temperature of over 5,000° F. A stream of water joins the flame, and the combined effect is to disintegrate the rock into fragments, which are blown from the cut. The vertical channel is made from an open face by guiding the nozzle up and down in an arc. The process has been in use too short a time to permit reliable determinations of rate or cost of cutting. The noise made is so deafening that the operation is confined to night shifts.

Primary Separations

The first step in quarrying exposed rock is to make a primary break or cut that will separate a block of granite from the parent ledge. Joint systems as described in an earlier paragraph, should be utilized as fully as possible, but if such natural planes of separation are not available a cut or fracture must be made. This is sometimes done by discharging light powder charges in several deep-drill holes. The charge should be just large enough to make a fracture without shattering the rock. Such fractures are made if possible in the direction of easy splitting known as rift described in a following paragraph.

To conserve rock many operators prefer to make primary cuts by a drilling and broaching method. Using a reciprocating drill mounted on a bar, deep holes are drilled close together in a straight line. The webs between them are removed with a drill or a flat broaching tool substituted for the drill. Thus a narrow, continuous channel is made. As mentioned previously, any strain in the rock must be first relieved.

Hollow drill steel and detachable bits are commonly used. One of the greatest advances in drilling during recent years is the use of detachable tungsten carbide bits. The first cost is high, but the tool is economical because of the rapid drilling rate and the large accomplishment per bit. The amount of drilling accomplished varies with different granites. In the Barre, Vt., district a bit may require conditioning after each 50 feet of drilling. but it will complete 500 to 600 feet of drill hole before it is worn out. In the West Chelmsford district, Massachusetts, the accomplishment per bit is somewhat lower. Drilling and broaching have been standard practices in most quarries for many years.

Recently jet piercing has been substituted for drilling and broaching at Salisbury, N. C. This is the flame-drill method referred to previously; in North Carolina it is called jet channeling. A channel 3-1/2 to 4 inches wide is said to be cut 8 times faster than it could be cut by drilling. Wide substitution of jet channeling for pneumatic drilling is forecast by a leading stone producer for the near future.

The most modern method of making primary cuts is by using the wire saw. This equipment consists of a three-strand or single-strand wire that runs as a belt under tension. When fed with sand, aluminum oxide, silicon carbide, or other cutting agent carried in a stream of water it cuts a narrow channel by abrasion. This equipment has been used in the slate quarries of Pennsylvania for many years but it has been in granite quarries only recently. At West Chelmsford, Mass., it is now used for making nearly all rock subdivisions in the quarry. The wire used there consists of a twisted ribbon of high-carbon steel with the twist reversed every 50 feet to promote straight cutting. This is the so-called single-strand wire. It is about 3/16 inch in diameter and makes a cut about 1/4 inch in width, which becomes somewhat narrower as the wire wears. Sand is used as an abrasive in slate sawing, but granite is so hard that sand is ineffective, and granular aluminum oxide about 40-mesh or, in some granites, 60- to 120-mesh is used. It is recovered in a sump and reused until worn out. The wires are carried on 5-foot sheaves. To minimize wear on the wire, each wire is 16,000 feet long; it costs about 2-1/2 cents per foot.

For deep cuts structural-steel masts 70 or 80 feet high have been designed to carry fixed sheaves at the top and also to support a movable platform carrying sheaves that guide the wires as they enter and leave the cut. This platform moves down as the cut progresses. Tension is maintained with a car to which weights hanging over the quarry face are attached.

A typical arrangement of the equipment recently observed consisted of a gang of 4 wires spaced 3 feet apart operating on a bench 110 feet wide and 70 feet high. The wires were descending at a rate of 1-1/2 to 2 inches an hour. The wire-cut surface is smooth and requires little if any subsequent finishing except when a polished surface is required. By judicious spacing of the wires, millwork is greatly reduced. For instance, the 3-foot block cut in the quarry simply requires splitting in the center to make two 18-inch curbstones.

The quarry is equipped with a gang of 4 wires, 1 of 3 wires, and also doubles and singles. A maximum of about 12 wires could be operated if necessary. Figure 2 shows a gang of 4 wires spaced 3 feet apart. The wires entering the cuts appear at the right. Figure 3 illustrates the smooth surfaces obtained in wire-saw practice. Single wire saws are said to have been used with success in one Barre, Vt., quarry for some years.

When a primary cut is completed, the next step is to separate the rock mass at the quarry or bench floor. In most quarries natural horizontal partings are present in the form of sheeting planes, which simulate joints having an approximately horizontal attitude. Where present they greatly facilitate quarrying, as they constitute a ready-made floor separation. If these planes are absent or widely spaced, floor breaks must be made. This is done by driving wedges in horizontal drill holes at the base of the rock mass.

In some quarries in Georgia both sheeting planes and joints are absent or very widely spaced. In such deposits artificial sheeting planes are sometimes made before vertical subdivisions are attempted. This is done by discharging many successive small charges of explosive in the bottom of a drill hole 10 or 12 feet deep, thereby starting a horizontal fracture that gradually works outward. When it reaches a radius of 50 to 100 feet, the end of an air line is cemented in the drill hole with molten sulfur, and the sheeting plane fracture is completed with compressed air at a pressure of about 100 pounds per square inch. This method can be used only in areas that have no vertical joints through which the compressed air could escape.

In opening up a new bench on the floor of a pit quarry the first step is to obtain a trench in which to place wire saw masts or to conduct drilling and wedging operations to obtain floor breaks. A mass of rock at least 4 to 5 feet wide and the depth of a bench must be removed to give the necessary working space. This may be done by making two parallel channels by drilling and broaching and removing the rock between them. The mass of rock between the cuts may, with care, be separated as quarry blocks and utilized. Such trenches are commonly made during the process of relieving strain.

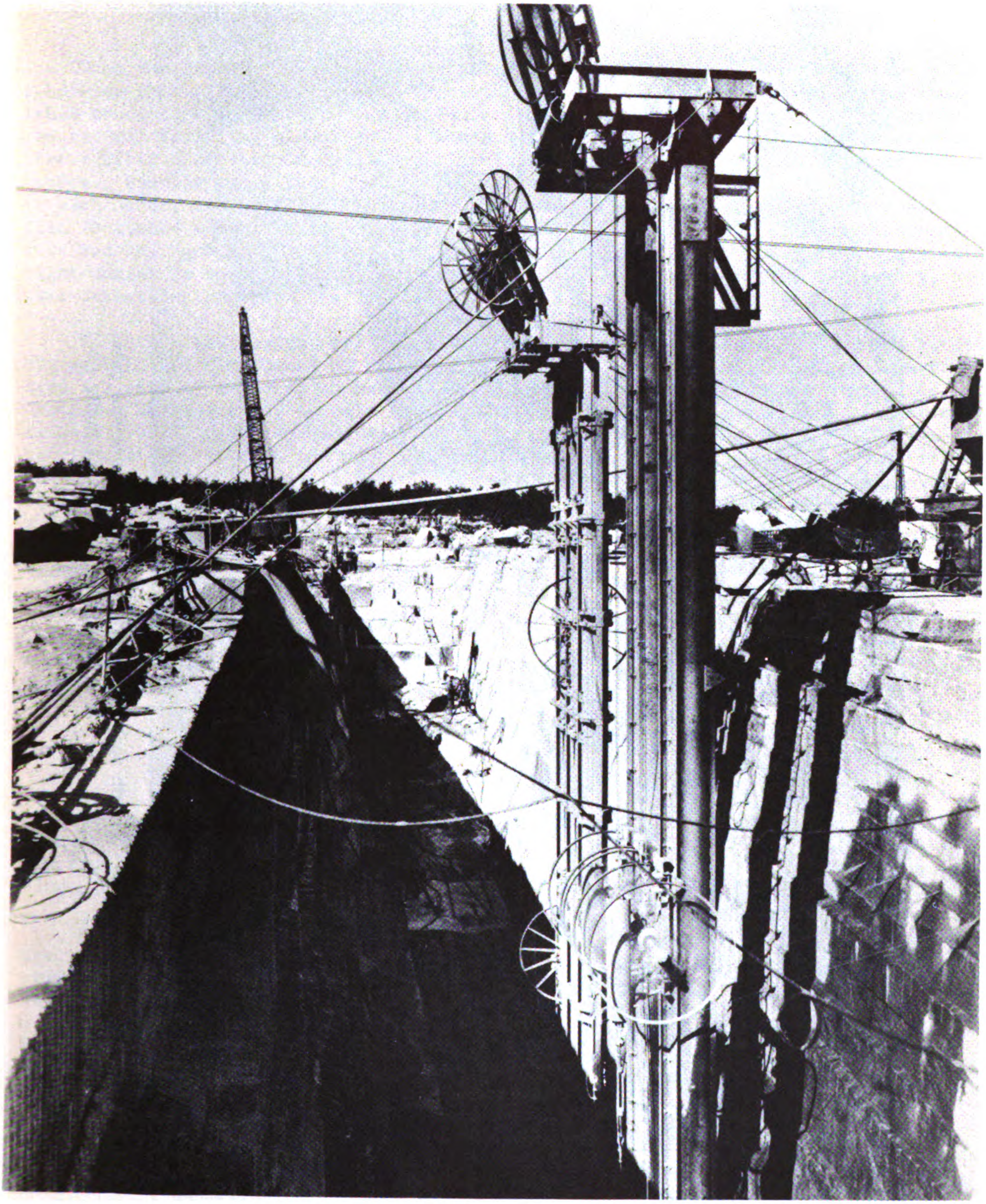

Figure 2. - Wire saws in operation in a granite quarry.
(Courtesy, H. E. Fletcher Granite Co.)

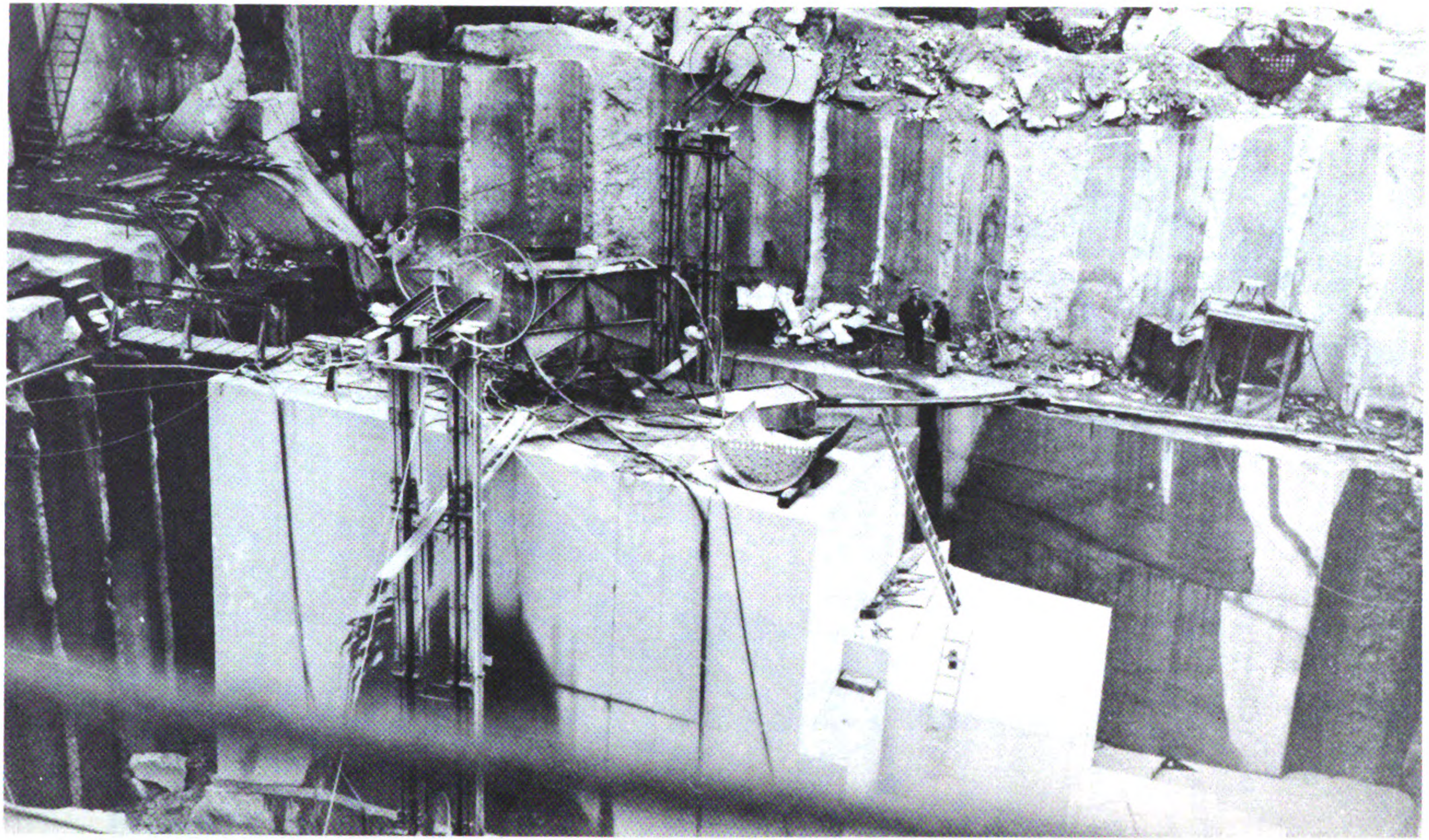

Figure 3. - Smooth surfaces obtained by making wire-saw cuts.
(Courtesy, H. E. Fletcher Granite Co.)

Secondary Subdivisions

When the larger masses are separated from the solid ledge, the next step is to subdivide them into blocks of the approximate sizes and shapes desired in the finished product or into convenient sizes for removal from the quarry. In this process the natural splitting directions of the rock must be taken into account. Most granites exhibit a tendency to split with greater ease in certain directions than in others. Usually two directions of easy splitting are approximately at right angles to each other, one of them being more pronounced than the other. The easier direction is termed the "rift." The second direction is termed the "run" in some localities and the "grain" in others. In the third direction, which is approximately at right angles to both rift and run, the rock splits with the greatest difficulty, and this direction is termed the "hard way."

To obtain the easiest splitting and the smoothest surfaces the major fractures are made in the directions of rift or grain. Compressed-air drills of the hammer type are usually employed to make a row of holes along the line where a break is desired. The holes may be only 4 inches deep and several inches apart. The break is made by driving "plug-and-feather" wedges in the holes. The feathers consist of two iron strips flat on one side for contact with the wedge and curved on the other to fit the wall of the drill hole. They are placed in the hole and the plug - a steel wedge - is placed between them. They are sledged lightly in succession until a fracture appears.

Block Removal

Fixed derricks are usually employed for hoisting rough blocks from deep quarries and placing them on trucks for haulage to the finishing mill. Movable derricks mounted on caterpillar-tread bodies have been introduced in some areas. In shallow quarries where moderate grades are possible truck haulage is employed.

FINISHING PROCESSES

Block Subdivision

Quarry blocks are made into finished products, such as building units, curbstones, or monuments, in finishing mills that may or may not be associated with quarries. Granite blocks may be subdivided into desired shapes and sizes by driving plug-and-feather wedges in shallow drill holes, or they may be subdivided by sawing.

Although it is expensive, sawing has definite advantages. Thin slabs of granite, which could not be profitably shaped in any other way, are easily obtained by sawing. Furthermore, the most attractive surface on some granites is parallel with the hard way. By ordinary methods of splitting with wedges it is impractical to obtain blocks having their larger surfaces parallel with this direction, but by sawing such surfaces are obtained as easily as those in any other direction. Sawing also conserves rock by reducing waste.

Three principal types of saws are in use in modern granite mills - circular saws, gang saws, and wire saws.

A typical circular saw, as used at Barre, Vt., is 11 feet in diameter. It is equipped with moderately hard, detachable steel teeth, and steel shot fed to the saw with water is the cutting agent. The granite blocks are set in line on a traveling bed, and the spaces between them are filled with plaster of paris, which holds the abrasive in the cut as the saw passes from one block to another. The rate of sawing is 1 to 2 inches a minute through blocks 24 to 36 inches thick. Such saws are used only in the larger mills.

Gang saws have been used for many years. They consist of a series of soft steel blades set in a frame that has a backward and forward motion. When a block of granite is placed beneath the frame the blades, fed with steel shot and water, will make parallel cuts of any desired spacing. The rate of cutting in ordinary mill blocks is 4 to 9 inches an hour, depending upon the hardness of the granite and other factors. The abrasive is collected in a sump and redistributed.

Wire saws are now used in many finishing mills. As observed in a mill at Barre, Vt., 4 wires each 1,050 feet long were making parallel cuts in a block about 10 feet long. The sawing rate was about 12 inches an hour when aluminum oxide abrasive was used and 15 inches when silicon carbide was employed. A wire will make about four such cuts before it is worn out. The power requirement is about 10 hp. per wire.

The cost of wire sawing per square foot of surface obtained is considerably higher than when gang saws are used, but there are compensating advantages. First, the wire saw makes a cut only 1/4 inch wide, whereas the gang-saw cut is at least 1-1/4 inches wide. Thus the wire conserves much valuable stone on which a great deal of labor has already been expended. A second advantage is the smooth surface resulting from wire saw work. The surface-finishing cost is much lower than when gang-sawed blocks are used.

Surfacing

Where rough quarry stock is dressed into building stones without sawing, the first step in manufacture is termed "lining," which consists in working the edges of the block to the required dimensions. This is usually done with pneumatic tools. The next step is to dress the faces to the edge dimensions. This is generally done with a surfacing machine, which essentially consists of a reciprocating tool covered with blunt projections. As the machine is guided over the surface it chips off fragments of stone, gradually working the surface down to an even plane. A heavy tool is used to remove the larger irregularities and a lighter tool with smaller projections to give a tooled-surface finish. The exposed face is commonly left with a rock-cleft surface.

Polishing

If a polished surface is desired, the blocks from the surfacing machine, or those cut with saws, are placed in groups of 8 or 10 on a timber bed with their upper surfaces on an even plane. The rectangular group of blocks is surrounded with a wooden box, the bottom of which is a little lower than the stone surfaces, and all cracks in the box and between the blocks are filled with plaster of paris. A belt-driven revolving head known as a scroll, consisting of a series of concentric or spiral iron rings, is guided over the surface. It is fed with abrasive and water; the rings are designed to keep the abrasive under the scroll as long as possible and make it cut effectively. For rough surfaces steel shot is employed as abrasive, but for smooth, wire-cut surfaces the steel-shot stage may be omitted. As the surface becomes smoother, silicon carbide is used, followed by fine-grained aluminum oxide. The final polish is accomplished with putty powder consisting essentially of tin oxide carried under a rotating felt pad.

Sand Blasting

Much of the carved work done with hand or pneumatic tools in early years is now done by sand blasting. A polished granite surface on which an inscription is to be cut is first covered with a rubberlike compound known as "dope," or with heavy adhesive tape. Lettering or other designs are imprinted on the coating; and, with a sharp tool like a scalpel, the coating is removed from all parts that are to be cut below the surface. Where uniform lettering is needed, the process is simplified by using a die for each letter. A hammer blow on a hot die outlines the letter with double cuts that pass through the coating to the stone surface. A sharp spatula is used to pick out the pieces of tape between the cuts.

Stone thus prepared is placed in an illuminated closed chamber, with the surface to be carved vertical and facing the operator who observes it through a window. A nozzle, through which compressed air at a pressure of 80 to 100 pounds per square inch drives a stream of fine sand or powdered silicon carbide, is held through a curtain, which protects the operator from the abrasive dust. When the sand blast is directed against the design the exposed granite is quickly cut away, and the sand has little or no effect on the surface coating. Certain parts of letters or designs may be cut 1/2 to 1 inch in depth. Design cutting may be done in successive stages. Remarkable precision and fineness of detail are possible. Rose petals may be cut so thin that they are almost transparent.

Other Operations

Carborundum wheels are employed in various ways in granite-finishing mills, but cutting must be done carefully and with an abundance of water. Some mills are equipped with turning lathes for shaping and polishing granite columns and spindles.

TARIFF

The United States Tariff Act of 1930 provided for an import duty of 60 percent ad valorem on manufactured and 25 cents per cubic foot on unmanufactured granite. The rates established by the Tariff Act of 1930 have been modified considerably by trade agreements. By virtue of a trade agreement with Sweden dated August 5, 1935, the duty on granite paving blocks was reduced from 60 to 40 percent ad valorem. A Finnish agreement dated November 2, 1936, reduced the duty on all granite hewn or dressed from 60 to 30 percent ad valorem. The duty was reduced to its present rate of 15 percent ad valorem pursuant to concessions made under the General Agreement on Tariffs and Trade (GATT) effective June 6, 1951. The duty on unmanufactured granite, which had been reduced from 25 to 20 cents a cubic foot under the Swedish trade agreement, was further reduced to 12-1/2 cents under the Finnish agreement. It was reduced to its present rate of 10 cents per cubic foot by GATT concessions effective April 30, 1950.

FOREIGN TRADE

Imports of granite are attaining increasing importance; the value of imports in 1954 exceeded 1 million dollars, nearly three-fourths of which was the value of dressed stone. Most of it came from West Germany. Part of that received from West Germany consisted of Swedish granite fabricated in German mills. Finland and Belgium are other important sources of finished granite. Norway and Sweden are the chief suppliers of rough granite blocks. Figures for total imports are recorded each year in the Stone chapter of the Minerals Yearbook, volume I.

PRICES

The average selling price, per cubic foot, of rough architectural granite has ranged from $1.82 to $2.44 f.o.b. quarry, and of dressed building granite from $6.58 to $8.48 at finishing mills associated with quarries during recent years. Corresponding figures for rough monumental granite were $3.28 to $3.78 and of dressed monumental granite from $10.55 to $11.56. Curbing values ranged from $1.80 to $2.87 per cubic foot at the quarry. Delivered prices of all these products at the point of consumption would be much higher.

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